2003

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In Iowa, alluvial aquifers near major rivers are a source of water for many communities. The City of Cedar Rapids withdraws water from wells completed in the Cedar River alluvium, a shallow alluvial aquifer adjacent to the Cedar River. The City of Cedar Rapids is located within Linn County in east-central Iowa, and water for the City is supplied by four well fields (East, Northwest, Seminole, and West well fields) along the Cedar River. The City has a population of about 121,000, and several large industries are major water users. Currently, per capita water usage in the City is nearly three times the national average. The City is committed to providing both a high quality and quantity of water to its customers. The USGS and Cedar Rapids Water Department have been working together in an ongoing research program to better understand water quality and flow in the Cedar River and alluvial well fields. Work has been done on both a basin and well-field approach and has involved dye tracing/time-of-travel studies on the Cedar River, water-quality sampling, geochemical modeling, and groundwater-flow modeling.

The effect of land use in the Cedar River Basin on both surface-water and groundwater quality is an important issue. The Cedar River Basin upstream from Cedar Rapids is approximately 6,500 square miles. Upstream land use in the Cedar River Basin is over 90-percent agriculture. Corn and soybeans are the major crops. Livestock raised in the area include beef and dairy cattle, as well as hogs. Runoff from agriculture is of concern, particularly during the spring and early summer when many chemicals are applied to cropland. Triazine and acetanilide herbicides are commonly applied in the Cedar River Basin, and these herbicides are water soluble and can be transported to streams and infiltrate to groundwater. In addition, several studies in eastern Iowa have identified nutrients as a major contaminant that has impaired water quality (Goolsby and Battaglin, 1993; Hallberg et al., 1996; Schnoebelen et al., 1999; Kalkhoff et al., 2000). In general, the majority of nitrogen inputs in the Cedar River Basin are from chemical fertilizers and animal manure (Becher et al., 2000). High nitrate levels (greater than 10.0 mg/L) in the Cedar River are of particular concern to municipal water operators. The lower Cedar River is listed on the Iowa total maximum daily load list for nitrate upstream of Cedar Rapids, Iowa. The Cedar River is the

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THE SECOND INTERNATIONAL RIVERBANK FILTRATION CONFERENCE: RIVERBANK FILTRATION: THE FUTURE IS NOW! PROGRAM & ABSTRACTS, Cincinnati, Ohio, September 16-19, 2003.
Edited by Gina Melin. Published by the National Water Research Institute.

source of most nitrate detected in the Cedar River alluvial aquifer because of induced infiltration from the river due to pumping (Schulmeyer and Schnoebelen, 1998; Boyd, 2000).

An unconsolidated surficial layer of glacial till, loess, and Cedar River alluvium (alluvial aquifer) overlies carbonate bedrock of Devonian and Silurian age (bedrock aquifer) in the study area. The alluvial aquifer typically consists of a sequence of coarse sand and gravel at the base, grading upwards to finer sand, silt, and clay near the surface. The sand and gravel contain carbonate, shale, and ferro-magnesium rich rock fragments. The thickness of the alluvial aquifer ranges from about 2 to 30 m. The alluvial aquifer is recharged by the infiltration of water from the Cedar River, precipitation, and seepage from the underlying bedrock and adjacent hydrogeologic units. In areas under the influence of municipal pumping, groundwater flow is from the Cedar River toward the well fields; in areas outside the influence of municipal pumping, groundwater flow is toward the Cedar River. Results from a regional groundwater flow model indicated that approximately 74 percent of the water pumped from the alluvial well fields is recharged from the Cedar River, approximately 21 percent is recharged from adjacent underlying hydrogeologic units, and approximately 5 percent of the water is from infiltrating precipitation (Schulmeyer and Schnoebelen, 1998). Currently, a more detailed groundwater model in the study area indicates that, in some places, up to 90 percent of the water pumped from the alluvial well fields is recharged from the Cedar River.

The water quality in the alluvial aquifer within the well field has been characterized with samples collected from both monitoring and municipal wells at various times since 1992 (Boyd, 2000; Schulmeyer and Schnoebelen, 1998; Schnoebelen and Schulmeyer, 1996). Calcium, magnesium, and bicarbonate are the dominant ions. In addition, nitrate, sulfate, silica, iron, and manganese are present in significant concentrations in certain wells or at certain times of the year. Previous work in the Seminole well field indicated some detections of herbicides and their degradates (breakdown products) in shallow monitoring wells (3.8- to 6-m deep) completed in the alluvium as water moved from the river into the alluvial aquifer (Boyd, 2000). Atrazine was the most commonly detected herbicide in this study. Acetochlor, cyanazine, and metolachlor were also detected, but at smaller concentrations than atrazine. Acetanilide degradates were detected at greater frequencies and at greater concentrations than their corresponding parent compounds. Fewer numbers of detections of herbicide compounds were found in wells completed deeper in the alluvium.

The infiltration of water with large nitrate concentrations into the alluvial aquifer from the Cedar River affects groundwater quality. Recent research was conducted along a flowpath to study RBF through a natural wetland area. Groundwater modeling helped locate the flowpath study. The study examined the role of a natural wetland in reducing nitrate concentrations as water moves from the Cedar River. A real challenge for the Cedar Rapids Water Department is the increasing trend of nitrate concentrations in the Cedar River. Nitrate concentrations in the Cedar River during the spring are often more than 10 mg/L and can reach 20 mg/L. A 2- to 3-mg/L reduction in nitrate often occurs as water moves from the river to the well, but in some wells, this may not reduce nitrate concentrations below the 10.0-mg/L maximum contaminant level. Sampling in wells along a flowpath occurred quarterly over a period of about 4 years. A comparison of water chemistry was made from water analyses from:

- The river.
- A monitoring well upgradient of the wetland area and river.
- Wells in the wetland area.
- Wells between the wetland area and river.

In addition, a comparison of water-chemistry data from a municipal well located near the wetland area and one located nearest the river were compared in terms of water chemistry from previous sampling work (Schulmeyer and Schnoebelen, 1998). Results show that nitrate concentrations were 4 to 6 times lower in samples from monitoring wells completed in the wetland area than in the Cedar River or groundwater in the upland area; however, iron and manganese concentrations in samples from the monitoring wells in the wetland areas were an order of magnitude higher when compared to the river or upland well. Water samples from the wells and the Cedar River generally displayed similar trends (high in the spring and low in the fall), while iron and manganese concentrations were more variable.

As water moves from the river towards the monitoring wells, microorganisms obtain energy for metabolic processes by catalyzing the oxidation of organic matter with a progressive series of reducing reactions (Stumm and Morgan, 1981). Nitrate can be reduced to elemental nitrogen (N_2) by denitrification (Equation 1) or to ammonium (NH_4+) by reduction (Equation 2). Since ammonium was only detected in small quantities (less than 0.80 mg/L), denitrification most likely is the predominant process.

$$4NO_3^- + 5CH_2O + 4H^+ = 2N_2(g) + 5CO_2 + 7H_2O \qquad \text{(Equation 1)}$$

$$NO_3^- + 2CH_2O + 2H^+ = NH_4^+ + H_2O + 2CO_2 \qquad \text{(Equation 2)}$$

Reduction then proceeds from nitrate (NO_3^-) to Mn^{+4}, Fe^{+3}, SO_4^{-2}, CO_2, and N_2. The reduced forms of iron (Fe II) and manganese (Mn II) are more soluble in water and are more mobile than oxidized forms (Hem, 1985) and, under anoxic conditions, are stable. As nitrate in groundwater is depleted, iron and manganese reduction begins. The reduction of Fe^{+3} to Fe^{+2} and Mn^{+4} to Mn^{+2} from aquifer grain coatings can cause large concentrations of these ions in groundwater. Ferrihydrite and manganite (MnOOH) occurring as oxyhydroxide coatings on clay and silt particles are the most likely oxidized forms of iron (Fe^{+3}) and manganese (Mn^{+3} and Mn^{+4}) in the alluvial aquifer. Oxidized forms of iron and manganese might occur in the aquifer as crystalline minerals, such as hematite (Fe_2O_3) and hausmannite (Mn_3O_4). Iron and manganese may co-precipitate with carbonate minerals to cause well fouling.

Research in the Seminole well field indicates that the location of a well in or near natural wetland areas may benefit from the natural reduction of nitrate concentrations, with the disadvantage of increased iron and manganese concentrations. Future expansions of the well fields may take advantage of natural wetland areas to help reduce nitrate concentrations. In Iowa, most wetlands have been drained, but alluvial wetlands associated with bottomland forested and oxbow lake areas may persist as they are subject to periodic flooding and are often not suitable for sustained agriculture.

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DOUG SCHNOEBELEN is a Research Hydrologist with the United States Geological Survey and has worked on a variety of groundwater and surface-water projects over the last 13 years. He has served as the groundwater specialist on the White River National Water Quality Assessment project in Indiana and as the surface-water specialist for the Eastern Iowa Basins National Water Quality Assessment project in Iowa. In addition, he has been the Iowa District Water-Quality Specialist since 1994, and is an Adjunct Professor in the Geoscience Department at the University of Iowa. His research has focused on the use of isotopes and bore hole geophysics in groundwater and, more recently, on the fate and transport of agricultural chemicals in surface water and groundwater across eastern Iowa. In particular, he has focused on the fate and transport of several pesticide degradate compounds. He has been involved with ongoing research in riverbank filtration and geochemical modeling in the Cedar Rapids well field since 1999. Schnoebelen received a B.S. in Geology from the University of Iowa, an M.S. in Geology from the University of Tennessee, and a Ph.D. in Geology, with a minor in Environmental Science, from Indiana University.